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Risk-Reduction Strategy**

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NASA'S ORBITAL SPACE PLANE RISK-REDUCTION STRATEGY

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Abstract

This paper documents the transformation of NASA's Space Launch Initiative (SLI) Second Generation Reusable Launch Vehicle Program under the revised Integrated Space Transportation Plan, announced November 2002. Outlining the technology development approach followed by the original SLI, this paper gives insight into the current risk-reduction strategy that will enable confident development of the Nation's first orbital space plane (OSP). The OSP will perform an astronaut and contingency cargo transportation function, with an early crew rescue capability, thus enabling increased crew size and enhanced science operations aboard the *International Space Station*. The OSP design chosen for full-scale development will take advantage of the latest innovations American industry has to offer. The OSP Program identifies critical technologies that must be advanced to field a safe, reliable, affordable space transportation system for U.S. access to the Station and low-Earth orbit. OSP flight demonstrators will test crew safety features, validate autonomous operations, and mature thermal protection systems. Additional enabling technologies may be identified during the OSP design process as part of an overall risk-management strategy. The OSP Program uses a comprehensive and evolutionary systems acquisition approach, while applying appropriate lessons learned.

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Revised Integrated Space Transportation Plan

In November 2002, after a series of Agencywide comprehensive studies performed by both internal and external review teams, NASA updated its Integrated Space Transportation Plan (ISTP) to reflect the priorities and realities of current U.S. missions and markets. ISTP is NASA's broad strategy to ensure safe, reliable, and affordable space transportation systems are available to support U.S. missions. Within the ISTP are two high-priority areas: (1) The Space Shuttle Service Life Extension Program (SLEP) and (2) the restructured Space Launch Initiative (SLI). Both are united in the "One NASA" spirit, with SLEP managed by NASA's Office of Space Flight and SLI managed by the Office of Aerospace Technology, with work distributed throughout NASA's field Centers.

Also in 2002, the Agency's overriding mission to safely deliver astronauts to the *International Space Station (ISS)* and return them to Earth emerged as a top priority along with upgrading the Shuttle's aging technologies to complete Station assembly. Subsequently, SLI was divided into two areas: (1) The Orbital Space Plane (OSP) Program for assured access to the Space Station and low-Earth orbit, and (2) the Next Generation Launch Technology (NGLT) Program to advance the technologies identified through SLI research. This paper focuses on the technology approach being implemented by the OSP Program and how that differs from the approach taken by SLI's Second Generation Reusable Launch Vehicle (2nd Gen RLV) Program, which laid the groundwork for the current OSP and NGLT Programs.

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OSP Program Goals and Objectives

The 2nd Gen RLV Program architecture design contracts and existing flight demonstration projects were transitioned to the OSP Program, and advanced technology development projects, such as main propulsion, were transitioned to the NGLT Program. The OSP will complement and back up the Space Shuttle by taking crews to and from the Station as well as enable a transition path to future reusable launch vehicles (RLVs) that will benefit from NGLT research.

In the OSP development cycle, around 2010, the OSP will be used as a crew rescue vehicle, initially launched on a human-rated expendable launch vehicle (ELV). As the NGLT Program progresses, the OSP may one day fly on a new reusable booster system. To deliver in a timely manner, the OSP will be based mainly on existing technologies, with select advancements in the areas of crew safety, thermal protection systems (TPSSs), and autonomous operations.

NASA has established a baseline for concise OSP Level 1 Requirements (Fig. 1) and initiated focused concept studies through existing architecture contracts.

Level 1 Requirements simply identify top-level specifications without dictating a design solution, of which there are many under study (Fig. 2). Therefore, the trade space is wide open for each competing contractor to present detailed development and operations plans for an optimum system that meets NASA's mission requirements.

Throughout this process, the OSP team benefits from improved business systems and management of technologies that are greatly advanced compared to previous launch system developments. It draws upon an extensive lessons learned database and employs industry experts in a range of fields to bring the best ideas to the table in an integrated fashion.

The OSP Program risk-reduction strategy includes a number of elements, from using rigorous systems engineering to Earned Value Management in order to closely track progress against an Integrated Master Baseline Schedule. A process is in place to conduct trade analyses as system designs are matured and to identify potentially enabling, crosscutting technologies that may need to be developed. An acquisition strategy is being formulated to transition the best technologies from the private sector and similar Government systems development programs. Computer modeling and simulations will be validated by ground-based testing and, in some instances, flight testing in real-world operational conditions for critical technologies, such as crew safety features.

Selection of Enabling Technologies

The Space Station Program is the primary customer for an OSP. The OSP Program translates customer needs into realistic requirements and prevents requirements "creep" from degrading the Program's focus. The OSP Program continually assesses risk, cost, and schedule against OSP mission requirements and success criteria and ensures that sound, robust processes and tools are in place to enable safe and successful missions. Based on current and historical information, it performs technical assessments, applying weighted criteria to identify areas that will be good investments, promise to lower development and cost risk, and can be reasonably expected to result in a value-added product to be incorporated into the OSP.

The OSP Program ensures that NASA's requirements drive its management philosophy. It also defines, analyzes, controls, and maintains those requirements throughout the system design process. System requirement integration is supported by technical documentation under configuration control. The Program also evaluates requirements for compatibility, and performs design concept validation and verification. Engineering trade studies and analyses provide information for key OSP decisions at critical milestones:

- System Requirements Review (SRR): October–December 2003.
- System Definition Review (SDR): April–June 2004.
- Full-Scale Development (FSD) Decision: Fall 2004.
- Preliminary Design Review (PDR): March–April 2005.
- Critical Design Review (CDR): January–March 2007.

An analysis cycle (AC) process (Fig. 3) has been established to evaluate projected system performance against required capabilities and operational scenarios to identify technology gaps. The process consists of four main components: (1) Planning, (2) assessments, (3) issue resolution, and (4) documentation.

High-fidelity data validate requirements and designs to ensure that Program goals are met. If there are fully crosscutting enabling technologies that can support Program cost and schedule goals, then the advanced development needs process can identify promising, nearly mature technologies worthy of funding.

The accelerated pace of technological advancement and the shift of critical technologies development from the Government to commercial industry means that NASA must: (1) Leverage the best technology available from both sectors, (2) rapidly transition the technology into new transportation systems, and (3) refresh this technology as needed to maintain

Orbital Space Plane Program Level 1 Requirements

MISSION NEEDS STATEMENT

The vehicle(s) and associated systems will support U.S. *ISS* requirements for crew rescue, crew transport, and cargo.

REQUIREMENTS

1. The system, which may include multiple vehicles, shall provide rescue* capability for no fewer than four *ISS* crewmembers as soon as practical, but no later than 2010.
2. The system shall provide rescue capability that allows the safe return of deconditioned, ill, or injured crewmembers with ongoing treatment until arrival at a definitive medical care facility within 24 hr. The crew should not require suits in the vehicle, but the vehicle should support the crew wearing suits if the situation warrants.
3. The system for rescue shall provide for rapid separation from the *ISS* under emergency conditions followed by their return to Earth.
4. Safety requirements—system for crew rescue:
 - (a) The availability (defined as “a full-up vehicle able to perform its mission”) for the escape mission shall be at least:
 - (i) Objective: 99%.
 - (ii) Minimum threshold: 9%.
 - (b) The risk of loss of crew shall be, with high confidence, lower than the Soyuz for the rescue mission.
5. The system shall provide transportation capability for no fewer than four crewmembers to and from the *ISS* as soon as practical, but no later than 2012.
6. Safety requirements—system for crew transport: The risk of loss of crew shall be, with high confidence, lower than the Space Shuttle for the transport mission.
7. The system shall be designed for minimum life cycle cost.
8. The system shall meet all applicable *ISS* requirements for visiting and attached vehicles.
9. Compared to the Space Shuttle, the system shall require less time to prepare and execute a mission and have increased launch probability.
10. Compared to the Space Shuttle, the system shall have increased on-orbit maneuverability.

OPERATIONS CONCEPTS

1. The vehicle(s) shall initially launch on an ELV.
2. The system shall be operated through at least 2020; however, the system should be designed so that it could be operated for a longer time.
3. NASA envisions that the system for crew rescue and crew transport could be different versions of the same vehicle design.
4. The system shall provide contingency capability for cargo delivery to or from the *ISS* to support a minimal level of science.
5. The system shall support a nominal *ISS* crew rotation period of 4–6 months.

*Rescue includes medical evacuation and emergency evacuation.

Fig. 1. OSP Level 1 Requirements.



Fig. 2. Competing aerospace industry contractors will present detailed OSP system designs.

advantages astronauts and operational support personnel need throughout the life of a system.

Acquisition Management and Technology Development

The acquisition and application of technology influences the entire life of a major program—from identifying and applying commercial and Government science and technology, to enabling technology tradeoffs with the requirements community, to continuously integrating the technology into development programs, to integrating the technology into production and operations systems, to continuously evolving the technology for future systems, and finally, to retiring the technology and attendant systems.

The Program's comprehensive and evolutionary systems acquisition strategy fosters its overall development approach while applying appropriate lessons learned from

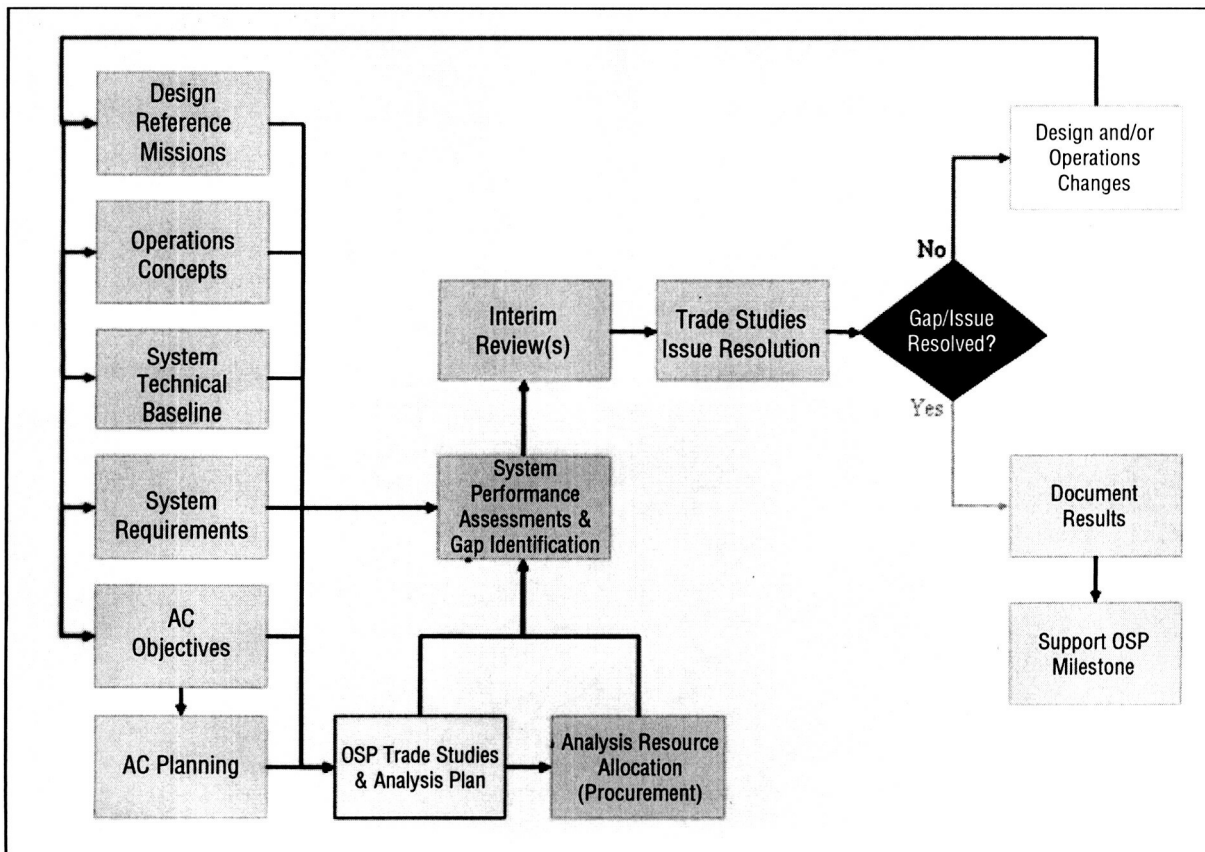


Fig. 3. Analysis cycle process.

successful programs in other Government agencies, such as the Department of Defense's (DoD's) Joint Strike Fighter and the Coast Guard's Deep Water Cutter. Agile acquisition is a method to field today's technologies as soon as possible—even at a 70–80 percent readiness level—through disciplined and discriminate technology transition instead of delaying deployment until the technology is already outdated. This approach warrants an incremental delivery schedule, perhaps even spiral development processes, which fosters acquisition flexibility. For NASA and the OSP Program, this means acquiring the capabilities to satisfy OSP Level 1 Requirements by taking advantage of private-sector expertise.

The OSP Program established an Acquisition Management Office (AMO) to develop the acquisition plan and acquisition strategy, the Request for Proposal, and associated documents for the development phase. This entails addressing a number of policy, management, and technical issues. In addition, AMO will identify and evaluate options and make recommendations for the operations phase.

A preferred strategy for rapid acquisition of new crew transport/rescue vehicles uses an evolutionary approach that delivers capability in increments, recognizing, up front, the need for future capability improvements. The success of the strategy depends on the consistent and continuous definition of requirements and the maturation of technologies that lead to the disciplined development and production of systems that provide increasing capability toward an OSP concept.

Acquisition goals are to incorporate best management practices, reduce operations costs, reduce cycle time, and enhance cost credibility. One such best practice is cost as an independent variable (CAIV), a proven acquisition strategy for transitioning technology that balances the highest possible value-added technology for the end user with the most credible cost points. Objectives are to streamline management processes and decision times, establish accountability, reduce time and resources needed to perform the next flight, revitalize and retrain the workforce, improve communication, focus investments on top priorities, and improve service contract management.

Testing Advanced Technologies in Real-World Environments

NASA's OSP Program, chartered in November 2002, evolved from fundamental research done during the first 2 years of SLI, which was established in February 2000 to reduce the technical and business risks of developing a follow-on to the Space Shuttle. As part of that process, SLI's 2nd Gen RLV Program worked through hundreds of potential concepts that were designed to meet NASA, commercial, and DoD primary needs. As SLI progressed, market research concerning the declining satellite industry launch rate left the

commercial business case in question, and DoD missions were not sufficiently mature enough to specify exact requirements; therefore, NASA missions became the prime driver for the development of the OSP transportation system.

Over the first 2 years of SLI, the field was narrowed from hundreds to the best 15 candidates from three competing prime contractors—The Boeing Co., Lockheed Martin Corp., and Northrop Grumman/Orbital Sciences Corp. A significant conclusion that emerged from this fundamental work was that separating crew and cargo transport functions was a logical way to improve safety and reduce mission costs.

SLI's extensive systems engineering analyses identified the high-payoff technologies that must be developed to build and operate a new system that would be dramatically safer, more reliable, and less expensive to operate than the Space Shuttle. It became apparent that NASA must advance select critical technologies, such as crew enhancements, that will not be developed independently by the private sector without Government investment. Through a series of comprehensive reviews, investments were focused to support the crosscutting technologies identified.

Before a safer, more reliable, and cost-effective space transportation system can be built, enabling hardware and software technologies must first be tested in relevant environments to reduce inherent development risks. For example, autonomous rendezvous capability represents a critical area where the United States must gain badly needed experience before the first flight test of a new integrated space transportation system.

At the time of the SLI reorganization, two flight demonstration project contracts were awarded as part of NASA Research Announcement (NRA) 8–30, Cycle 2, to inform the OSP FSD decision and reduce the technical risk of building and flying a new generation of reusable space transportation. These projects are the X–37 Flight Demonstrator and the Pad Abort Demonstrator (PAD). The Demonstration of Autonomous Rendezvous Technology (DART) began with NRA 8–30, Cycle 1 awards in May 2001 and transitioned to the OSP Program in November 2002.

Validating ground-based testing and analysis is a necessary part of fielding a new space transportation system. Each of the OSP flight demonstration projects will produce data that can be directly applied to the entire range of potential system designs and was selected based on previous SLI studies that identified the most critical flight demonstration needs (Fig. 4). Each was selected under a full-and-open competition to produce the data that will reduce the technical risk of a particular aspect of the OSP system regardless of the design finally chosen for FSD.

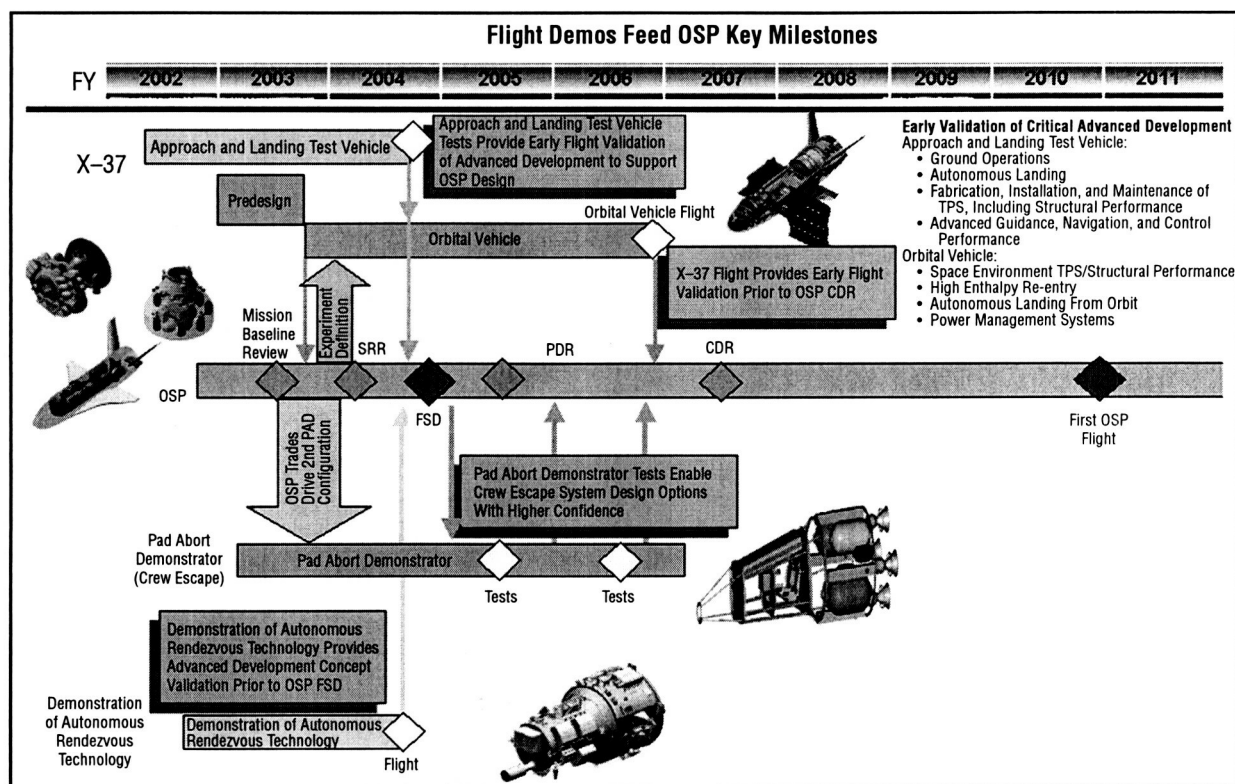


Fig. 4. Comprehensive linkage between OSP milestones and flight demonstration projects data.

Flight demonstrators represent a high-value investment when considering the potential total development cost of the OSP system. They will provide valuable quantitative data in support of the FSD decision and greatly mitigate risks during the development period. All flight demonstrators are crosscutting in nature and will provide technology data applicable to other potential future space transportation systems in addition to supporting the OSP Program.

X-37 Project

The X-37 subscale space plane is an integrated platform to validate a host of high-priority technologies in the orbital and reentry environments (Fig. 5). The X-37 will demonstrate the effectiveness of advanced TPSs, including high-temperature ceramic leading-edge material, durable high-temperature blankets, and metallic TPSs. Additional advanced TPS experiments may be incorporated based on technology maturity and mission profiles. It is imperative to test TPS in the reentry environment. A primary goal of the OSP is to improve operability and maintainability through such improvements.

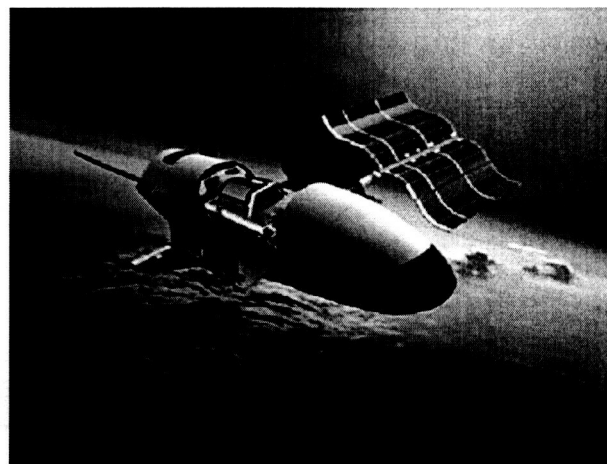


Fig 5. X-37 orbital vehicle (artist concept).

In 2001, the suborbital, 40,000 ft and below, phase of the X-37 Project resulted in a series of seven successful atmospheric tests of the 80-percent scale X-40A, which

netted performance data on computerized flight control systems; control room operations; and guidance, navigation, and control software.

The X-37 Project was originally a cooperative agreement between NASA, the U.S. Air Force, and Boeing. With NRA 8-30 funding awarded in November 2002, the X-37 vehicle assembly is progressing and will culminate in further suborbital testing before moving into the orbital flight phase (Fig. 6). Through drop-testing from a B-52 aircraft, a series of approach and landing tests will gather data to enable orbital flight testing from an ELV. Operating autonomously, the X-37 will test technologies in real-world conditions and generate information that directly applies to the OSP. Approach and landing data will be available in 2004, followed by orbital vehicle (OV) flight data in 2006.

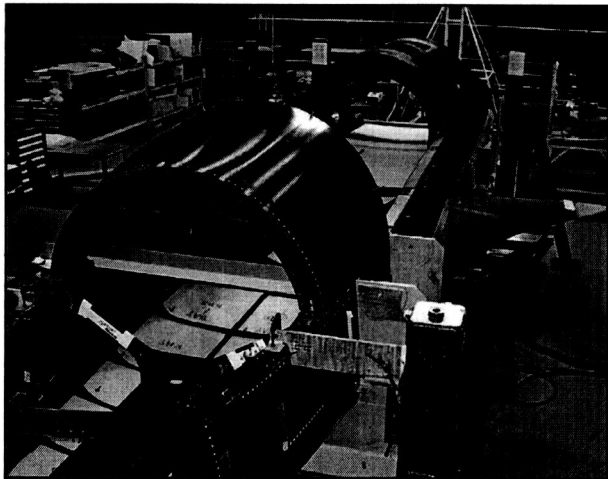


Fig. 6. Approach and Landing Test Vehicle assembly is now in progress.

Demonstration of Autonomous Rendezvous Technology Project

Since the 1960s, NASA has performed numerous rendezvous-and-docking missions. Recent examples include Hubble Space Telescope servicing and Space Station construction missions. While spacecraft piloted by astronauts have been the common element of all U.S. rendezvous-and-docking missions, currently, only the Russian space program performs autonomous rendezvous. As operations on the Station increase, the demand to autonomously transport science experiments and other cargo to and from the orbiting laboratory also increases.

The DART Project, a partnership between NASA and the Orbital Sciences Corp. that began during SLI, will demonstrate an in-space event of autonomous rendezvous and closed-loop proximity operations and control between the DART chase vehicle, now being developed, and a passive target satellite—a multiple paths, beyond-line-of-sight communications (MUBLCOM) satellite—that is already in orbit (Fig. 7). The DART will launch on a Pegasus small-payload rocket dropped from a high-altitude aircraft. The on-orbit mission scenario includes autonomous rendezvous from a parking orbit to a point in the vicinity of the target satellite, autonomous operations in close proximity to the target using navigation data provided by the advanced video guidance sensor (AVGS), recovery of autonomous operations following the disruption of AVGS data, collision avoidance maneuvers, and ground-controlled test simulations of on-orbit performance. Flight testing will validate ground-test results and software algorithms, and is essential to reducing the risk of building an OSP that can fly routinely without a pilot in the loop. DART results will be available in the 2004–2005 timeframe.

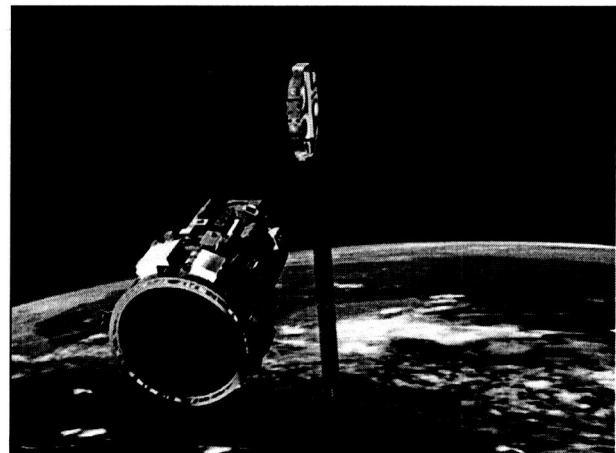


Fig. 7. DART will help establish U.S. ability to operate orbital vehicles remotely (artist concept).

Pad Abort Demonstrator Project

PAD, a partnership between NASA and Lockheed Martin and funded through NRA 8-30, Cycle 2, will provide a full-scale platform for measuring crew survivability design environments and assessing crew escape technologies in a launch pad abort situation. The United States has not designed or built any full-envelope crew-escape systems since the Apollo Program in the 1960s. The PAD Project will help reestablish the industry's capability to design and build crew escape and survivability systems utilizing current

technologies by performing an end-to-end launch pad abort demonstration. Fully instrumented mannequins will provide data on crew environments during testing of propulsion and parachute systems, orientation and landing techniques, and external structural configurations (Fig. 8). This important safety data will be available beginning in 2005.

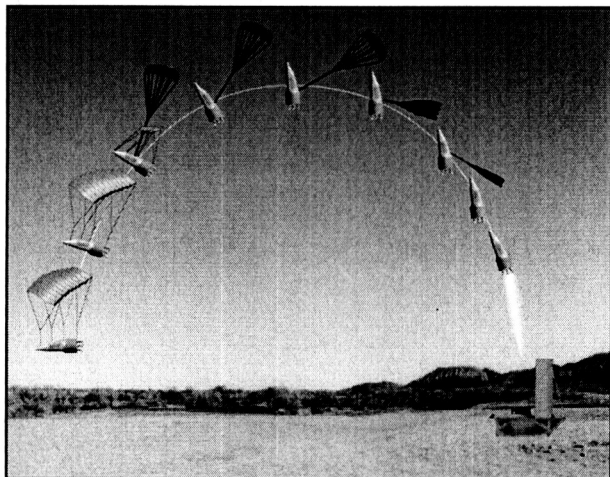


Fig. 8. PAD data will help establish new crew safety features (artist concept).

Conclusion: The OSP Is a Critical National Asset

NASA's SLI has matured from an extensive requirements definition and risk-based technology development effort to the OSP Program, which is fully focused on flight vehicle development. The OSP early capability enables U.S. obligations for Space Station crew rescue no later than 2010, followed by a crew and contingency cargo transport capability in 2012 (Fig. 9). In this way, the OSP builds a bridge to the future by enabling increased Space Station crew size and resultant science benefits.

The new system that results will offer operational flexibility for U.S. missions, increase safety, and complement the world's only RLV. This opens the possibility to use the OSP as the primary crew rescue and transport means while utilizing the Shuttle workhorse capabilities for large cargo, such as Space Station structural components.

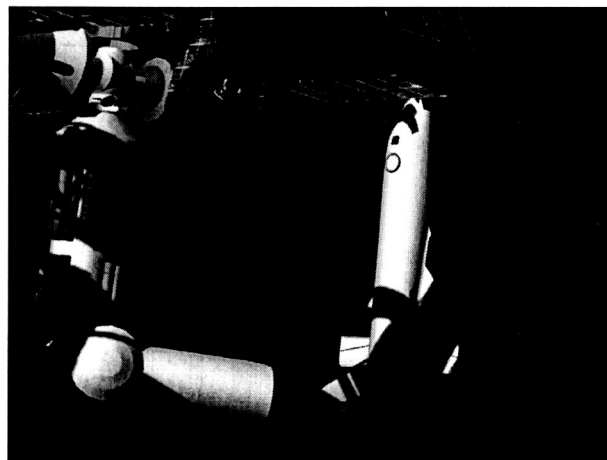


Fig. 9. The OSP will be a bridge to the Space Station (artist concept).

It has been 3 decades since the Shuttle was built; the OSP Program is helping the Nation rebuild its capability to build an integrated system that includes a myriad of details. The experience gained from designing and developing the OSP system will pave the way for future RLVs—both in terms of utilizing technology and adapting business models to a modern space transportation enterprise.

The OSP Program is challenged to simultaneously build an agile Government organization responsible for designing model acquisition systems to transition technology for the national space transportation infrastructure and to meet unprecedented deadlines within the national roadmap for assured access to space.

The OSP Program is a prototype for One NASA, with a lean, value-added approach. Flight demonstrator projects are poised to support the design contractors and reduce the risk of doing something entirely new in the space arena. Proven performance management systems, evolutionary acquisition strategies, and either spiral or incremental development for technology maturation will enable continued accountability, flexibility, and disciplined innovation in the design and development of a new national asset to inspire future generations and further expand the possibilities for research, exploration, and discovery.